Design of a TPC for EOS Studies at RIA

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Abstract/Summary: Rare isotope beams at RIA provide an exciting opportunity to place experimental constraints on the density dependence of the asymmetry of the nuclear equation of state (EOS). Calculations predict that measurements in central heavy ion collisions of the isospin dependence of π^+ and π^- production and comparisons of neutron and proton flow observables are particularly important because they display a sensitivity to the density dependence of the asymmetry term at above normal densities. A time projection chamber (TPC) is the logical device for measurements of the pionic observables and will enable the neutron and proton flow measurements as well. Design studies are needed to determine the required characteristics of a TPC for EOS studies at RIA. This will specify whether solenoidal or dipole geometry is more appropriate, whether the current ($4MD) cost estimate is appropriate and what is the floor space required for a TPC and the ancillary detectors required for EOS studies at RIA.

Description of R&D effort: The density dependence of the asymmetry term of the equation of state governs the proton fraction within a neutron star [1,2]. It influences the stability of nuclear matter with respect to the transformation to the strange or quark matter, the thickness of the inner crust of a neutron star, the neutron star radii and moments of inertia, and the cooling of the proto-neutron stars formed in a type II supernovae [1,2].

Nucleus-nucleus collisions have provided constraints on the equation of state of symmetric matter at densities of $\rho \leq 5\rho_0$ [3]. However, the asymmetry term itself is relatively unconstrained, even though its importance to the EOS of dense astrophysical sites is paramount [1,2]. Investigations of nucleus-nucleus collisions using the rare isotope beams at RIA provide unique opportunities to establish meaningful constraints on the density dependence of the asymmetry term. Constraints on the asymmetry term are needed for a range of densities. The behavior at high densities $\rho > \rho_0$ may be the region where present constraints are least stringent.

Calculations predict the relative concentrations of neutrons and protons within the dense matter formed in a central nucleus-nucleus collision to be sensitive to the density dependence of the asymmetry term [4]. This sensitivity results in a dependence of the relative production of π^+ and π^- upon the high-density behavior of the asymmetry term. In particular, an asymmetry term with a weaker density dependence results in a larger $Y(\pi^-)/Y(\pi^+)$ yield ratio [4]. Likewise, the difference between the neutron and proton transverse flow also depends on the asymmetry term [4]. Therefore, studies of the density dependence of the asymmetry term of the EOS require experiments capable of measuring π^+ and π^- yields as well as neutron and proton flows at a variety of impact parameters for a variety of colliding systems of differing total isospin asymmetry.

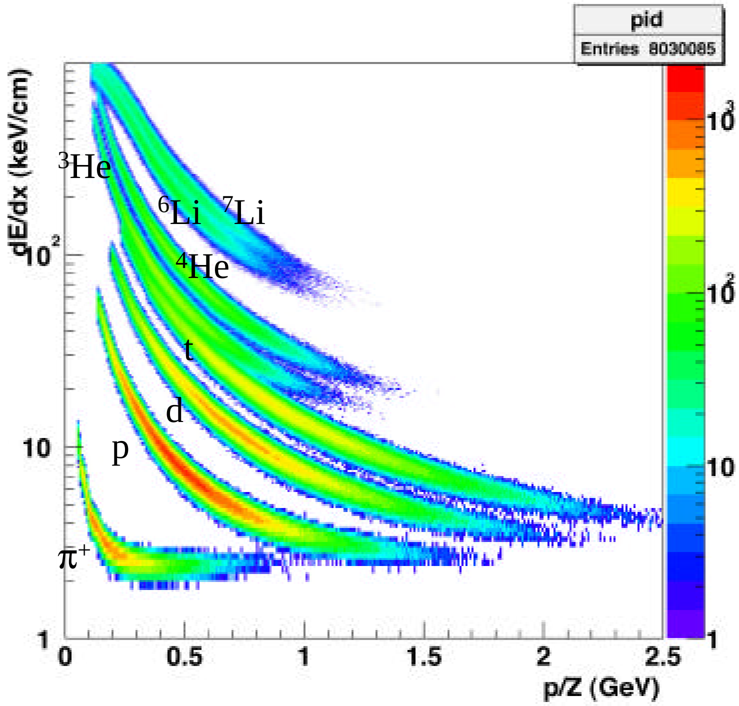

Fig. 1 Simulate PID for RIA TPC, assuming a performance similar to the STAR TPC.

A time projection chamber is the logical device for such studies. TPC's permit a straightforward particle identification of light charged particles, including pions and can be constructed with an open geometry that allows the detection of neutrons via time of flight. Figure 1 shows the result of a simulation of the particle identification one might expect for a TPC designed for RIA. Pions and the various isotopes of elements up to lithium are easily resolved. The appropriateness of a TPC for RIA is further bolstered by the successful establishment of constraints on the symmetric matter equation of state through measurements with the EOS TPC over a wide range of incident energies [5,6].

A preliminary cost estimate for a RIA TPC of $4MD was provided in March at the RIA detector workshop in Oak Ridge TN. This estimate is rather tentative because detailed simulations of pionic, neutron and proton flow observables have not been performed for the possible configurations for a TPC at RIA. The configurations, illustrated schematically in Fig. 2, are that of a dipole magnet with a field transverse to the beam axis (left side) or of a solenoid with a field parallel to the beam axis (right side).

Some of the advantages and disadvantages of each configuration are listed in Table I. In brief, the dipole geometry, utilized by EOS TPC [7], has the advantage of superior momentum resolution and detection efficiency for forward going particles. It has the disadvantage of being azimuthally asymmetric. In particular, particles close to the direction of the magnetic field have little momentum resolution, making elliptical flow analyses more difficult. The inclusion of a beam tube in the dipole geometry is difficult; indeed, the EOS TPC allowed the beam particles to traverse the active counter volume. In contrast, the solenoidal design, employed in the FOPI detector [8] or the STAR TPC [9],

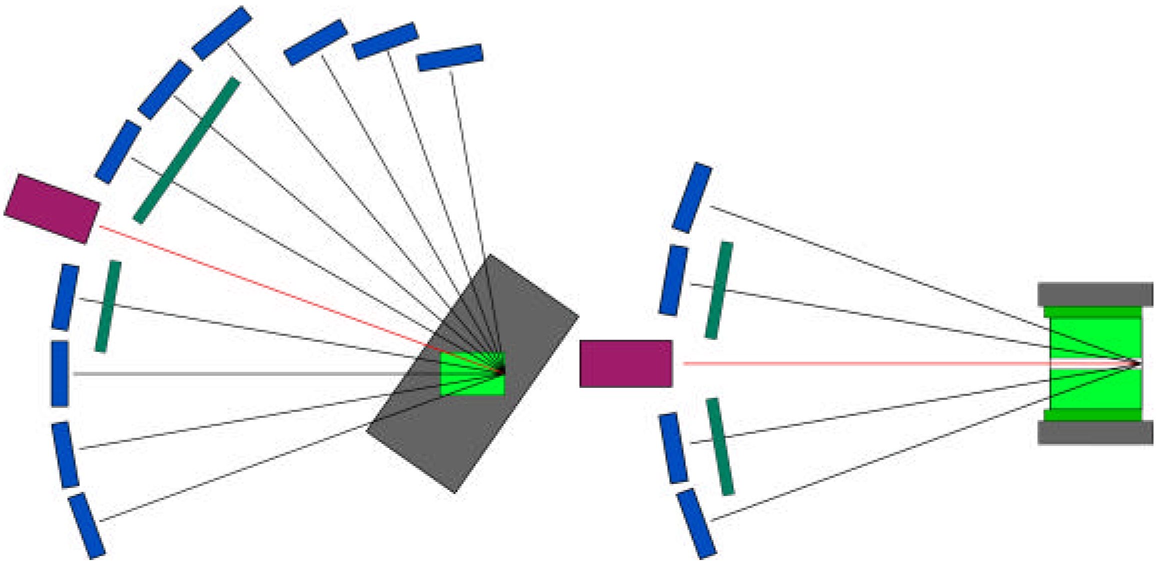

Fig. 2: Schematic representation of TPC layouts with magnetic field orientations perpendicular to the beam (left side) and parallel to the beam (right side). Also shown are schematic representations for ancillary MUSIC detectors (magenta rectangles), neutron detectors (blue rectangles) and possible time of flight detectors (dark green rectangles) that may be needed in actual experiments for triggering purposes.

accomodates easily a beam tube and is asymuthally symmetric. The momentum resolution for forward-going particles, which travel nearly parallel to the solenoidal magnetic field, however, is very poor or nonexistent.

Simulations are needed to weigh the relative merits of the two designs, as well as the size and footprint of the optimal magnet for each design. In addition, simulations must explore the requirements of the trigger system for the TPC, the technical demands posed by the large dynamic range of signals in the gas, and the coupling of the TPC to neutron detectors and to the Multi-Sampling Ion Chamber (MUSIC) [10] required for the detection and particle identification of projectile remnants of the collisions. While the location of the MUSIC is schematically represented in Fig. 2 to be well separated from the TPC, as it was during the experiments EOS at LBL, the large stopping powers of projectile remnants in the lower energy collisions at RIA will likely preclude passage though the air. Instead, a direct coupling of the TPC and MUSIC will probably be required.

These design studies will require about two (post-doctoral) man-years of effort. Clearly, this and other large detector projects are not critical to the successful production of rare isotope beams at RIA. However, timely initiation of these studies are necessary to ensure that the footprint of a TPC and its ancillary detectors can be accurately reflected in the civil engineering of the high energy experimental areas, and that the beam requirements and financial resources needed for the project can be accurately known. A decision to significant delay the initiation of design studies for complex detectors ignores the long time scales required for their completion and runs the risk that major experimental facilities will be unfinished when RIA produces beam. This eventuality, should it occur, would negatively impact the early discovery potential of the facility.

Design	Advantages	Disadvantages
Dipole	Good momentum resolution for momenta parallel to the beam. Possibly lower thresholds for particles moving parallel to the beam.	Incorporation of a beam tube is more difficult. Momentum resolution of the device is azimuthally asymmetric.
Solenoid	Easy incorporation of a beam tube into the design. Device is azimuthally symmetric, simplifying elliptical flow analyses.	Poor momentum resolution for momenta parallel to the beam. High detection thresholds for momenta parallel to the beam.

Table 1: Some advantages and disadvantages for each of the geometrical orientations of the TPC magnetic field geometry.

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